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INCIDENCE OF SLEEP LOSS AND WAKEFULNESS DEGRADATION ON A U.S. COAST GUARD CUTTER UNDER EXEMPLAR CREWING LIMITS

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16. Abstract (MAXIMUM 200 WORDS)

The goals of the USCG Exemplar project includes the exploration of the potential use of reduced crew complements aboard high endurance cutters. One major concern is that crew reductions may exacerbate crew fatigue and ultimately compromise safety. The central objective of this study was to determine whether crew members are experiencing unacceptable fatigue levels while sailing under Exemplar crew reductions. This study was conducted aboard the CG Cutter MUNRO (WHEC-378 foot) during a patrol from Tokyo, Japan to Pearl Harbor, Hawaii. Daily evaluations of alertness (maintenance of wakefulness) and of the stability of the sleep/wake cycle (variability of sleep duration and timing) were used to characterize fatigue levels throughout 30 consecutive days on patrol. Fourteen crew members participated in wakefulness maintenance tests consisting of the observation of the latency to sleep onset (as indicated by brain wave activity) while volunteers attempted to maintain wakefulness. Nine out of 14 participants failed to maintain wakefulness in 57 to 100 percent of the tests. Forty-three volunteers participated in daily sleep evaluations by wearing wrist-worn activity monitors 24 hours per day. Activity monitor data were used to document daily sleep onset times, wake-up times, and the stability of the sleep/wake cycle throughout the 30-day evaluation. Over sixty percent of all scored sleep profiles exhibited severe disruptions of sleep patterns. Correlation analysis confirmed that participants experiencing frequent disruptions of the sleep/wake cycle also suffered reductions of sleep below six hours and a high incidence of failure to maintain wakefulness above six minutes, signifying reduced alertness. Watch schedules requiring frequent rotations from daytime to nighttime (0000-0400) and early morning (0400-0800) duty hours contributed to the consistent disruption of sleep/wake cycles. The combination of current watch schedules, reduced personnel, and high operational tempo are expected to exacerbate the fatigue symptoms documented in this patrol. To minimize sleep/wake cycle disruptions, it is recommended that the frequency of rotation from daytime to night and early morning duty hours be reduced.

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EXECUTIVE SUMMARY

United States Coast Guard (USCG) missions often require rapid response, sustained operations, rapid transitions from daytime to nighttime duty hours, extended duty hours, and the implementation of rotating work schedules. The interaction of operational tempo, extreme weather conditions, sea states, crew experience, and work schedules can combine to reduce crew endurance, performance, and safety. Crew endurance depends on the ability to optimize crew rest, and on the prevention of shiftwork maladaptation (or Shift-Lag). Shift-Lag and lack of sufficient energy-restorative sleep induce fatigue (sleepiness, low energy, and lack of motivation), performance degradation during duty hours, and ultimately reduced safety.

Two experimental Coast Guard (CG) programs, namely Paragon (Atlantic Area 210 ft WMEC operations) and Exemplar (Pacific Area 378 ft WHEC operations) are exploring the potential use of reduced crew complements aboard cutters. One major concern is that crew reductions may exacerbate crew fatigue, and ultimately, compromise safety. Here, we present the results of the Exemplar fatigue evaluation study conducted aboard the USCGC MUNRO (WHEC 724) during a patrol from Tokyo, Japan to Pearl Harbor, Hawaii. The central objective of this evaluation was to determine whether crew members experienced fatigue levels that may result in reduced safety.

Volunteers were solicited from crew stations affected by reductions prescribed in the Exemplar program. All experimental procedures were reviewed and approved by a certified Investigations Research Review Board. A total of forty-five crew members volunteered to participate in the crew fatigue evaluation. All volunteers were in good physical condition, with no history of chronic health problems. All information collected was kept confidential. Volunteers were informed that they could withdraw from the study at any time without consequences of any type.

METHODS

Alertness Tests

We used electroencephalography (EEG) techniques to measure individual alertness. Fourteen of the original 45 volunteers participated in this alertness evaluation. Tests were conducted every three to five days (as permitted by duty cycles) within three hours of wake-up time from normal sleep. Prior to these tests, participants were first instrumented with electrodes, connected to a portable EEG system, and asked to rest on a comfortable bed in a dark room. They were instructed to close their eyes and maintain wakefulness by mentally fighting the tendency to fall asleep.

In clinical and experimental sleep laboratories a similar test (the Maintenance of Wakefulness Test or MWT) is used to document reduced alertness (Campbell and Dawson, 1997) and the effects of sleep disorders on daytime sleepiness (Carskadon, Dement, Mitler, and Roth, 1986). Healthy individuals, who sleep soundly and without disruption seven or more hours per night, maintain wakefulness for at least 15 minutes. Individuals suffering from severe sleep disorders or sleep deprivation cannot maintain wakefulness beyond 10 minutes. Significantly reduced alertness has been demonstrated in association with wakefulness latencies at or below 8.2 minutes (Campbell and Dawson, 1997), while pathological sleepiness has been correlated with latencies below five minutes (Carskadon et al., 1986).

Twenty-four Hour Sleep/Wake Cycles

Wrist worn activity monitors (the size of an oversize wristwatch) were used to document daily sleep/wake cycles. These devices were worn throughout the day, during work and sleep periods. Sleep/wake cycle data were collected from all 45 volunteers throughout 30 consecutive days. These data provide a daily history of activity and rest that facilitated the assessment of sleep disruptions as a function of exposure to variable duty cycles and watch schedules.

RESULTS

Analysis of sleep/wake cycles revealed a high incidence of sleep/wake cycle disruption (61.5 percent). Frequent changes in wake-up times and sleep disruption occurred in association with

sleep duration below six hours and with alertness degradation. Sixty-four percent of participants taking MWTs consistently exhibited sleep latencies indicating reduced alertness (less than 8.2 minutes) or pathological sleepiness (less than five minutes).

Participants working under non-rotating, stable watch schedules (e.g., permanent 0400-0800 watch) exhibited consistent patterns of sleep and wake-up times with sleep duration rarely below six hours. In contrast, participants exposed to frequently rotating schedules showed disrupted and fragmented sleep associated with the 0000-0400 and 0400-0800 watch schedules. These work schedules disrupted the organization of 24-hour or circadian sleep/wake cycles and resulted in sleep loss and alertness degradation (Shift-Lag symptoms). Recovery from this condition takes a minimum of three to four days of consistent wake-up times, daylight exposure, work schedules and sleep per night (preferably seven consolidated hours),. However, symptoms of fatigue (e.g., drowsiness during work hours) may be experienced for several days after the realignment of sleep and work schedules.

Examination of environmental conditions in sleeping quarters revealed the need to improve ventilation and personal space in enlisted quarters. Also, noise level measurements revealed a constant noise source of 80 dB(A) SPL in one berthing area originating from the ship's gyrocompass room. EPA hearing conservation guidelines recommend minimizing exposure to noise levels above 75 dB(A) (Environmental Protection Agency, 1978).

CONCLUSIONS AND RECOMMENDATIONS

Unremarkable weather conditions and low operational tempo characterized this patrol. However, evidence of fatigue, as depicted by high failure scores in the alertness tests and frequent disruption of sleep/wake cycles, was frequently detected. Based on this evidence, crew endurance levels during this low tempo patrol were considered less than optimal.

Operational situations involving increased tempo, deteriorating weather conditions, and reduced crewing are certain to exacerbate fatigue symptoms. The following recommendations are offered to improve endurance levels:

1) implement an endurance education program in the form of training on how to optimize sleep quality and prevent Shift-Lag;

2) design watch schedules that minimize sleep/wake cycle disruptions;

3) develop a system to optimize the number of watch qualified personnel underway to reduce the frequency of rotations into the 0000-0400 or 0400-0800 watch schedules;

4) implement physical improvements to sleeping areas to improve sleep quality.

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ACRONYMS

CDI	Circadian Disruption Index
CG	Coast Guard
dB	Decibels
EEG	Electroencephalography
MWT	Maintenance of Wakefulness Test
SLI	Sleep Loss Index
SPL	Sound Pressure Level
WHEC	High Endurance Cutter
WRI	Wakefulness Reduction Index

BACKGROUND

United States Coast Guard (USCG) mission objectives often require sustained operations, rapid transitions from daytime to nighttime duty hours, extended duty hours, and the implementation of rotating work schedules. Often, crew members are exposed to deteriorating weather conditions that have already compromised the safety of other vessels. Low tempo operations have the potential for rapid transition into heightened all-hands activities within minutes of receiving a rescue call or identifying a vessel to be boarded. In each mission, the interaction of operational tempo, weather conditions, sea states, crew experience, and work schedules impact crew endurance, performance, and safety.

Traditionally, cutters have adopted rapidly rotating shift work schedules and 24-hour on-call duty to meet mission readiness requirements. Even during periods of low operational tempo, these duty schedules can induce chronic sleep debt, disrupted sleep, disruption of leisure time, and lack of sufficient time off. The synergistic effect of these conditions can increase stress, deplete physical energy and mental ability, degrade performance, and increase the risk level during boardings and rescue missions. High operational tempo may require boardings and sorties after normal duty hours (1600), thus increasing daily work hours, sometimes, for several consecutive days (e.g., migrant relocation). If this condition becomes chronic, personnel may experience persistent fatigue symptoms, lack of physical energy, and deterioration of cognitive functions.

Two major contributors to the deterioration of performance and alertness are the accumulation of sleep loss (less than seven hours per day) and the disruption of the regulation of energy resources. Rotating duty cycles and on-call 24-hour duty days can result in drastic daily variations in bedtimes and rise times and in reductions of time available for sleep. As a society, we are aware of the impact of sleep loss on performance, but we are much less aware of the effects that drastic variations in sleep and rise times exert on daily availability of cognitive and energy resources.

During daytime duty hours, the body's biological clock system regulates rise and sleep onset times using the time of daylight exposure to set its internal timing. This system is a biological mechanism that synchronizes daily physiological and cognitive rhythms, thus regulating the availability of resources throughout the day. Exposure to daylight of approximately 1000 lux in

intensity (similar to the brightness seen at dawn) or greater, after awakening from daily nighttime sleep, sets the biological clock via the stimulation of light sensitive tissue (e.g., retina of the eye). Light sensitive tissue conveys a neural message to specific areas of the brain (e.g., deep brain nuclei) and to glands (e.g., pituitary, pineal) which constitute the human biological timing system. Consistent daylight exposure from day to day maintains the biological clock's timing and ensures that mental resources and physical energy will be regularly available throughout the day. However, experiencing daily and frequent changes in the timing of daylight exposure disrupts biological timing and results in the induction of sleepiness, performance degradation, insomnia, gastrointestinal disorders, and overall malaise. These symptoms are similar to those experienced by travelers who cross several time zones in a single day (Jet-Lag). When the disruption of the biological clock is induced by varying duty schedules and not by travel across time zones, the resulting condition is referred to as Shift-Lag (Kogi, 1985).

In 1998, two experimental programs, namely Paragon (Atlantic Area 210 ft WMEC operations) and Exemplar (Pacific Area 378 ft WHEC operations), explored the potential use of reduced crew complements aboard high and medium endurance cutters. These programs were designed to document the impact of personnel reductions on crew members' sleep and alertness. Degradation of sleep and alertness could negatively impact crew endurance and safety during long duration patrols.

In this report, we present the results of a study conducted aboard the CGC MUNRO (Exemplar program) throughout 30 days on patrol. The central objectives of this research were:

1) to document the incidence of sleep loss, sleep/wake cycle disruption, and daytime sleepiness among crew members, and

2) to recommend improvements to current underway crew endurance plans that may optimize crew rest and maximize alertness during duty hours.

METHODS

General Approach

This project was conducted during April and May, 1998, during CG operations between Tokyo, Japan and Pearl Harbor, Hawaii, aboard the USCGC MUNRO (WHEC 724). The research plan consisted of the evaluation of crew endurance by documenting alertness levels, daily sleep, and work/rest cycles throughout 30 days underway. Forty-five crew members of the CGC MUNRO volunteered to participate in the crew endurance evaluation, and 14 of these volunteers also participated in alertness evaluations involving the recording of brain activity during a wakefulness maintenance test.

Underway, data were collected by a research team consisting of United States Coast Guard Research and Development Center (USCG R&DC) staff and contract technicians. Written policies and procedures were examined to assess cutter organizational factors influencing operations. Environmental observations were used to identify factors known to interfere with sleep.

Procedures

In port familiarization phase and training

Prior to the underway evaluation, all participants were exposed to each phase of data collection in a sequence similar to the planned underway data collection procedures. Participants were originally asked to report for EEG testing within three hours after awakening from a normal night of sleep (considered normal by each individual). The EEG test was conducted only once for each participant during this phase.

We used this familiarization phase to make sure that participants had an opportunity to experience all aspects of data collection procedures, and to be able to ask questions about the procedures prior to implementation during the underway phase of the study. Similarly, we used this period of time to adapt the research team to the ship's environment and to effectively develop working relationships with the MUNRO's crew.

On patrol data collection

During the underway phase, all 45 participants wore wrist activity monitors (WAMs). WAMs were downloaded and re-initialized every five days. Every three to five days (depending on availability), the 14 volunteers participating in the alertness evaluations underwent a maintenance of wakefulness test (MWT) session within three hours after awakening. The test session required approximately 90 minutes, taking into account measurement of scalp recording sites, cleaning scalp sites, applying electrodes, calibration of electrophysiology equipment, data recording, debriefing, and electrode removal.

Participants

Forty-five crew members from the MUNRO (37 male and 8 female) ranging from 18 to 41 years of age volunteered to participate in the study. Thirty-nine participants successfully completed all phases of data collection. One volunteer withdrew midway through the patrol, while the records of five volunteers were incomplete due to equipment malfunction during the patrol. All volunteers were in good physical condition and maintained current medical files with the ship's medical staff.

Volunteers were briefed on the right to withdraw from the evaluation without consequences, confidentiality of the data, experimental procedures, and benefits and risks associated with participation in the study. After the research staff answered all questions and concerns about the study, volunteers were asked to sign an informed consent form prior to initiating their participation in experimental procedures. All participants received identification numbers that were used on all measures (e.g., in circadian activity profiles and EEG data) to identify his/her data throughout the study. Risks to participants were minimal because the research plan did not prescribe the use of any invasive techniques or require significant changes in their daily duty routines. The experimental procedures used to evaluate sleep and alertness were reviewed and approved by a certified Investigations Research Review Board provided by Battelle Seattle Research Center, Inc. in Seattle, Washington.

Alertness Evaluation

This evaluation documented personnel's ability to maintain wakefulness at times of the day when cognitive and physical energy should be available at peak levels. This period of time comprises the three hours following awakening from normal nocturnal sleep in personnel whose biological clocks are set to provide energy and cognitive resources during daylight hours. Personnel aboard the MUNRO, as well as on all other high and medium endurance CG cutters, are considered daytime workers who must endure working night watch schedules from time to time. Their biological timing is not modified to optimize work during nighttime duty hours.

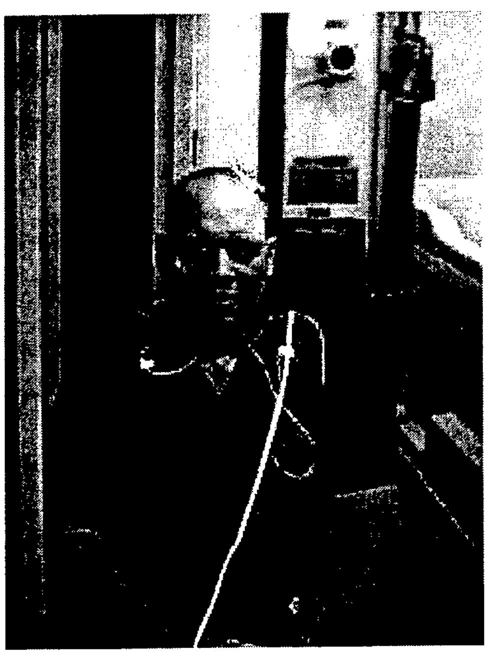
In clinical and experimental settings, sleep and wakefulness tests are used regularly to determine whether patients or test volunteers experience daytime sleepiness severe enough to compromise alertness and the ability to conduct activities that may affect individual or public safety (e.g., drive vehicles, decision making, etc.). These tests involve monitoring brain activity while patients attempt to maintain wakefulness (MWT) or to fall asleep (Multiple Sleep Latency Test or MSLT). During these tests, noticeable changes in brain wave frequencies indicate the exact moment of sleep onset (Campbell and Dawson, 1997; Pollak, 1997; Rechtschaffen and Kales, 1968). Sleep onset is scored by measuring the number of minutes that lapse from the beginning of the test (lights off in the test room) to the time of sleep onset. Sleep onset is determined by the detection of any of the five stages of sleep (Pollak, 1997; Rechtschaffen and Kales, 1968).

Healthy individuals who sleep soundly seven or more hours per night can be expected to maintain wakefulness in MWTs for at least 15 minutes. Campbell and Dawson (1997) recently showed that alert and healthy participants, adapted to nighttime duty hours, exhibited sleep latencies exceeding 15 minutes in MWTs (averages of 18.6 minutes at 0100 hour, 16.0 minutes at 0300 hour, 16.8 minutes at 0500 hour, and 17.1 minutes at 0700 hour). In contrast, participants working nights, but not physiologically adapted to nighttime work hours, consistently exhibited sleep latencies below 15 minutes (averages of 13.9 minutes at 0100 hour, 13.1 minutes at 0300 hour, 9.1 minute at 0500 hour, and 8.2 minutes at 0700 hour). Campbell and Dawson (1997) described these MWT latencies, and in particular those below 9.1 minutes, as indicative of reduced alertness.

In clinical settings, patients with sleep disorders that induce moderate daytime sleepiness usually fall asleep in less than ten minutes, while patients experiencing severe daytime sleepiness fall asleep in five minutes or less (Carskadon et al, 1986; Pollak, 1997). The latter may be a cause for train conductors, truck drivers, or pilots to be suspended from transportation duties until the condition is corrected.

The procedures used in the wakefulness evaluations aboard the MUNRO borrowed heavily from the clinical and experimental procedures used in the MWTs. The testing procedures used during the MWT are similar to those used by Campbell and Dawson (1997), while the scoring routines included information from Carskadon et al (1986), Campbell and Dawson (1997), and Pollak (1997). In this study, MWT latencies were documented at 10 minutes, 8.2 minutes, and five minutes. The 8.2 minute threshold was used to detect severe alertness degradation above the pathological threshold of five minutes, but equal with the alertness degradation lower bound (scores of 9.1 and 8.2 min) reported by Campbell and Dawson (1997).

Fourteen participants volunteered to undergo wakefulness test sessions. Participants were asked



to report to the testing environments (either a stateroom or the ship's clinic) within three hours of wake-up time every three-four days. This experimental constraint usually required volunteers to leave their departments during duty hours. Upon arrival at the test site, participants were first instrumented with electrodes (see picture at left), then connected to a portable electroencephalographic system (EEG), and asked to rest on a comfortable bed in a dark room (temperature maintained between 65 - 75°F). Brain wave activity was monitored continuously to detect the transition from wakefulness to sleep using a clinical methodology employed routinely in sleep laboratories (Rechtschaffen and Kales, 1968). Initially, participants were instructed to close their eyes and to allow themselves to fall asleep. They were allowed to

rest under these conditions for 15 minutes, but they were awakened in two minutes if brain wave frequencies indicated the onset of sleep. Following this initial period of rest, participants were asked to remain awake and to speak to the research staff for five consecutive minutes under lights on. These procedures helped to equalize participants' internal state and to control for varying emotional states associated with each volunteer's activity prior to the test. At the end of this break period, the lights were turned off again; participants were asked to lie down and to relax, but to try to remain awake. Brain wave activity was continuously monitored and used to determine the total time that each participant could maintain wakefulness during a 15-minute session.

Crew Endurance Evaluation

WAMs were used to collect volunteers' sleep/activity data throughout 30 days underway. A WAM is a wrist-worn unit (the size of an oversized wristwatch) with dimensions of approximately 4.5 cm x 3.4 cm x 1.2 cm. It consists of a battery-powered microprocessor with nonvolatile RAM, containing a piezoelectric motion sensor and a real-time clock. The unit can detect accelerations associated with physical activity from 0.5 to 3.2 Gz and compares each signal against a voltage threshold of detection.

WAMs were used to document daily sleep/wake cycles. Volunteers wore WAMs throughout the day, during work, leisure, and sleep periods. Activity data provided a history of sleep and wakefulness that could be used to determine the time of sleep onset, the number of awakenings throughout the sleep period, wake-up times, and sleep duration. The analysis of sleep/wake profiles yields specific information on:

1) daily changes in sleep onset and wake-up times,
2) number of awakenings during sleep,
3) incidence of disrupted sleep patterns, and
4) percent of sleep periods below six hours.

These observations are of vital importance because research on shiftwork, travel across time zones, and sleep disorders consistently associates fatigue and adverse health effects with frequent loss of sleep, poor sleep quality, and day to day changes in wake-up times (greater than three hours per day) (OTA report, 1991).

Environmental Observations

Researchers examined enlisted berthing areas to determine whether light and noise intrusions may have contributed to the disruption of sleep. Noise levels were measured in decibels (dB) using a sound pressure level (SPL) meter. The SPL meter was set to discriminate against energy content at low frequencies. This measurement of noise level is referred as the A-weighted sound pressure level in dB or sound level A or dB(A) (Lambert and Hafner, 1979). Multiple measurements were obtained from large berthing areas. The SPL meter was held by the experimenter at a point equidistant from each bunk approximately five feet from the floor of the berthing area. In large berthing areas, the room was divided in subsections to allow the placement of the SPL meter at equidistant locations from each bunk. At each location sound pressure levels were recorded at 125 Hz, 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz, 8 kHz.

Experimenters examined personal space to determine whether the clearance from the surface of a bunk to the bottom of the next bunk (placed one above the other) was sufficient for personnel to shift body positions during sleep.

RESULTS

Alertness Evaluation

Wakefulness maintenance tests

On patrol, fifteen volunteers participated in evaluations of alertness involving MWTs. One volunteer (number 17) withdrew midway through the patrol, thus reducing the total number of volunteers completing the study to 14.

Initially, the number of MWT scores were calculated to determine the incidence of scores identified as below normal in clinical settings.

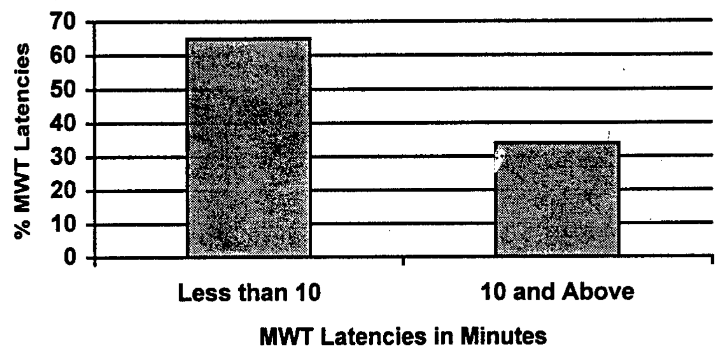


Figure 1. Percentage of MWT latencies. A total of 83 tests were administered throughout the patrol, 54 observations were below 10 minutes.

Considering that Campbell and Dawson (1997) reported alertness degradation with MWT scores below 15 minutes, the sixty-five percent of MWT scores (a total of 54 scores) below 10 minutes (shown in Figure 1) indicated a high incidence of alertness degradation among the test group. The 54 scores below 10 minutes were further subdivided into two categories: 5 minutes or less, and above 5 minutes. The greater majority of scores were found below the clinically pathological threshold of five minutes (see Figure 2). In clinical settings, this level of alertness degradation suggests the influence of a sleep disorder that severely impairs performance and safety.

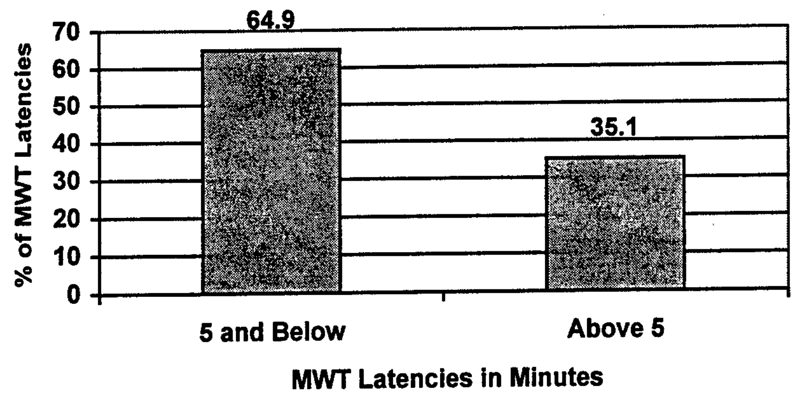


Figure 2. Percentage of MWT latencies plotted above and below the clinical threshold (five minutes).

Lastly, for each participant, the percentage of MWT scores at or below 8.2 minutes was calculated to further qualify the level of alertness degradation experienced throughout the patrol. The 8.2-minute threshold indicated degradation of alertness at either pathological levels (at or below five minutes) or at levels indicating shiftwork maladaptation as reported by Campbell and Dawson in the 1997 report. Figure 3 depicts the percent of MWT latencies below 8.2 minutes for each of the 14 participants aboard the MUNRO.

Please refer to Table A-1 (Appendix A) for specific information on the raw data values, percentages, and number of observations associated with each value plotted in Figure 3. Throughout the 30-day test period, participants were tested from five to seven times.

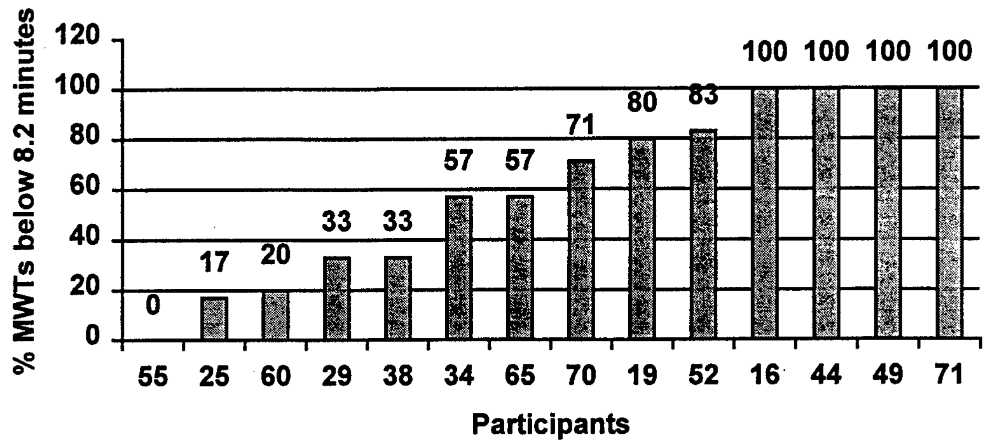


Figure 3. Wakefulness reduction index (percent of tests below 8.2 minutes) plotted for each volunteer participating in the MWT.

For each participant, a wakefulness reduction index (WRI) score was calculated by determining the percent of tests with MWT scores below 8.2 minutes. Only one participant (55) was able to remain awake in all test trials. Participants 25 and 60 exhibited minimal alertness degradation (failure rates between 17-20 percent), while cases 29 and 38 showed a moderate increase in alertness degradation with failure rates at 33 percent. In contrast, the remaining nine participants exhibited evidence of alertness degradation with failure rates between 57-100 percent of the trials (see Figure 3). Note that participants 16, 44, 49, and 71 were unable to maintain wakefulness for more than 8.2 minutes in 100 percent of all alertness trials.

Crew Endurance Evaluation

<u>Underway sleep/wake profiles</u>

Wrist worn activity monitors were used to document daily sleep/wake cycles. These devices were worn throughout the day, during work and sleep periods. Sleep/wake cycle data were collected from volunteers aboard the MUNRO throughout 30 consecutive days.

Sleep/activity data were plotted as a function of time of day to create a 24-hour or circadian (circa = about, Diem = day) record of high and low activity. Circadian activity records were

stacked sequentially to produce a history of sleep and activity for each participant (see Figure 4). Clock times presented at the top of the figure indicate the passage of time from left to right. Each horizontal line represents a day.

Time Line: Zulu + 10 hours

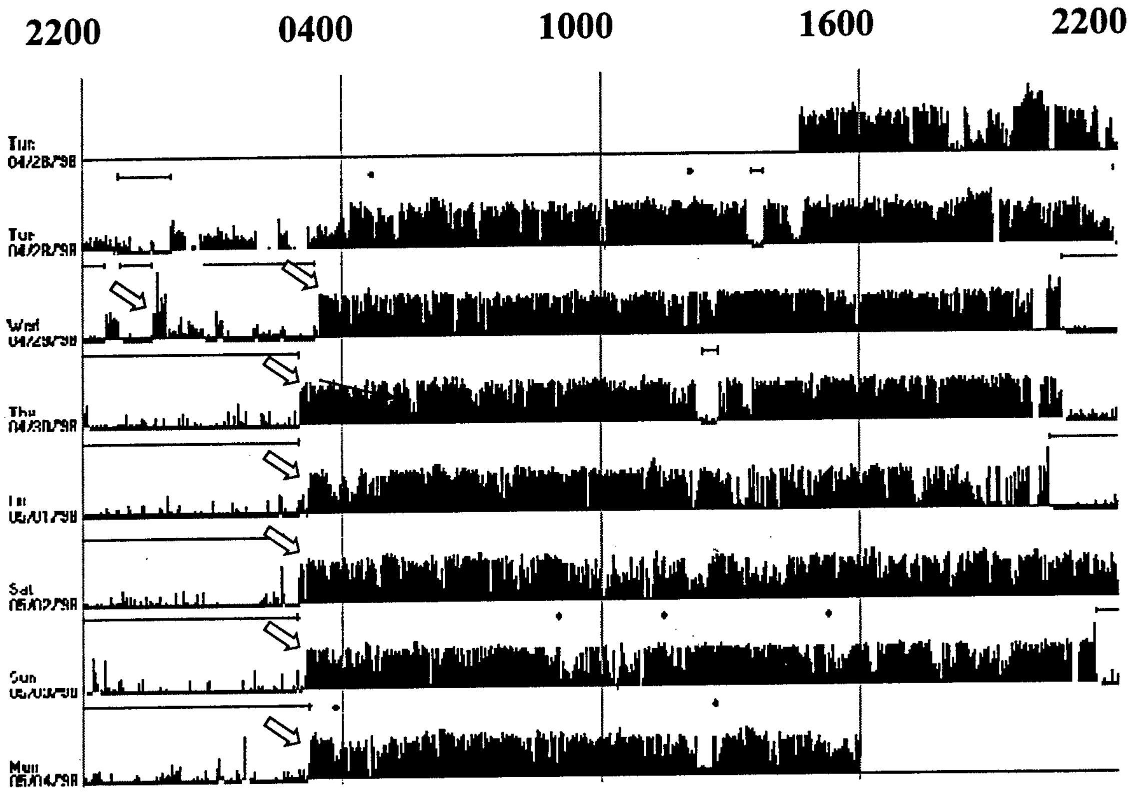


Figure 4. Activity data (obtained from a wrist activity monitor) plotted as a function of time of day. Vertical lines indicate activity. A high frequency of activity denotes wakefulness (see arrows). An absence, or substantial reduction of vertical lines, indicates sleep (also shown by horizontal lines above the sleep period). This record shows seven consecutive days for one participant, and depicts a well-adjusted sleep/wake cycle in response to always being on the 0400-0800-watch schedule.

Each row of Figure 4 shows sleep and wake periods. The vertical lines indicate levels of activity. A high frequency of activity counts denotes wakefulness. Please scan down between 0400 and 1000 and note the vertical lines plotted close together. This is characteristic of high activity levels and of wakefulness. The absence or substantial reduction of vertical lines indicates sleep (see Figure 4, fourth-eighth lines down, from 2000-0330). Sleep periods have been highlighted in

Figures 4, 5, and 6 by a horizontal line above periods of substantially reduced activity. High activity levels during sleep are evidence of awakenings and of sleep disruption (see Figure 4, second-fourth lines down, from 2200-0330). Figures 4-6 depict individual profiles for each of three participants exposed to different watch schedules aboard the MUNRO.

Time Line: Zulu + 10 hours

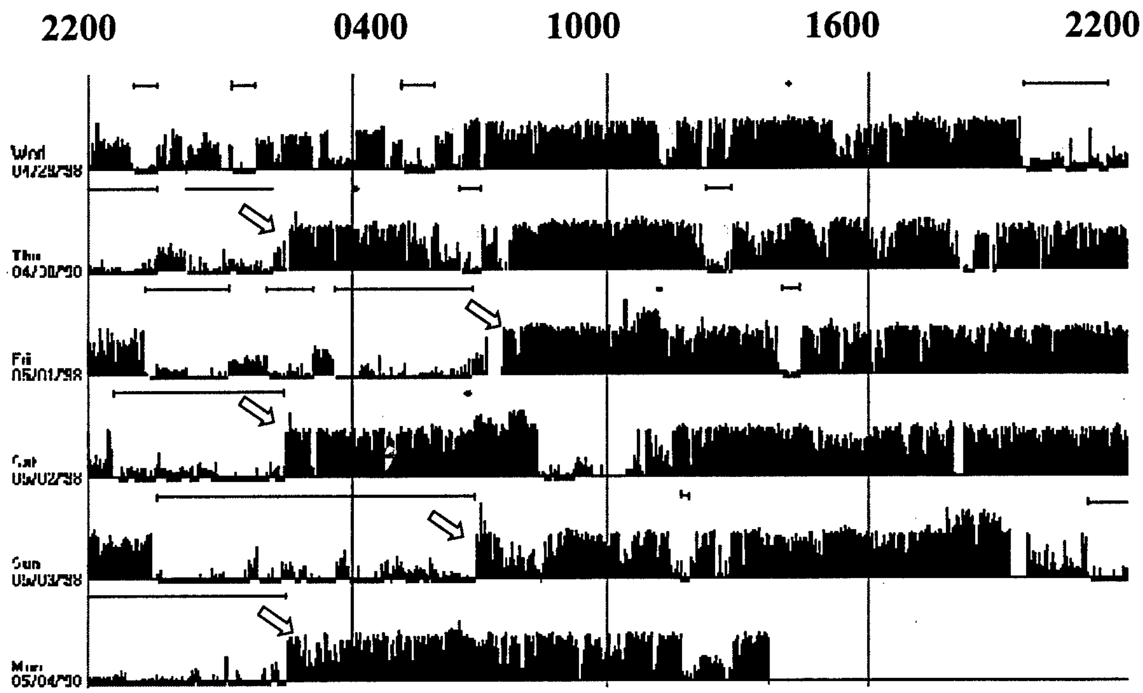


Figure 5. The induction of Shift-Lag via the use of watch schedules that prescribe the 0400-0800 schedule every other day. This pattern prevents the biological clock from establishing a steady state synchronization in phase with the work/rest schedule. Note the daily shifts in wake-up times (see arrows).

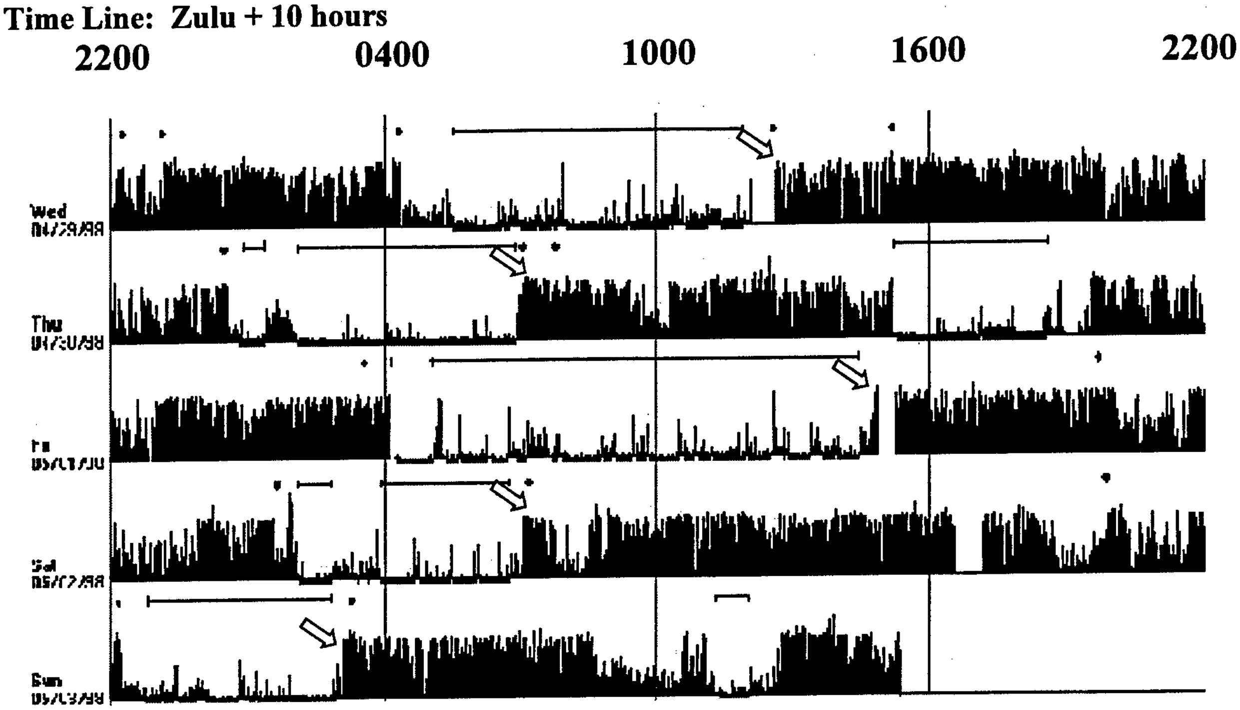


Figure 6. The induction of Shift-Lag by alternating the 0000-0400 watch (first and third days); daytime duty hours (second and fcurth days); and the 0400-0800 watch (fifth day) within a five-day period. This watch schedule resulted in daily shifts of wake-up times (see arrows) and in the splitting or fragmentation of the sleep period (second day, horizontal lines mark two sleep periods).

Figure 4 shows bedtimes, wake-up times, and sleep duration characteristic of normal sleep as this crew member established good habits to adjust to the 0400-0800 daily watch schedule. Note that beginning on the second day, wake-up time (denoted by the increase in activity) occurs consistently before 0400, indicating that this participant's work schedule began at approximately 0330. In contrast, the patterns depicted in Figures 5 and 6 illustrate the disruption of the sleep/wake cycle induced by changing work schedules. In these cases, sleep and wake-up times change as a function of varying work schedules (Figures 5 and 6) and sleep periods exhibit frequent disruptions (denoted by increased activity) and fragmentation (see Figure 6).

Figure 5 depicts the induction of Shift-Lag via the use of watch schedules alternating the 0400-0800 watch with daytime duty hours. This pattern prevents the biological clock from

establishing a steady state synchronization of physiological rhythms with work and rest schedules. The human body requires consistent daily inputs (e.g., bedtimes, wake-up times, and times of daylight exposure) to establish stable energy restoration cycles and meet the demands of daily periods of high activity. Alternating every other day between early and late morning wake-up times results in inconsistent inputs to the biological clock and prevents the establishment of stable sleep/wake cycles. The biological clock responds to these inputs as it would to the changes associated with frequent flights between the U.S. East and West coasts within a seven-day period. Similarly, Figure 6 illustrates the induction of Shift-Lag by alternating the 0000-0400 watch (first and third days), daytime duty hours (second and fourth days), and the 0400-0800 watch (fifth day) within a five-day period.

These work schedules induce disruption of the 24-hour sleep/wake cycle (i.e., the biological clock) and result in alertness reduction during duty hours. Recovery from this condition takes a minimum of three to four days of consistent wake-up times, daylight exposure, work schedules, and sleep per night (preferably at least seven consolidated hours),.

Sleep wake cycle disruption, sleep loss, and alertness

Analysis of circadian sleep/wake profiles provided quantifiable evidence of the degree of stability or disruption of daily sleep. Daily sleep duration, the frequency of awakenings during consolidated sleep, and the frequency of changes in wake-up times and bedtimes throughout each circadian sleep/wake profile provided evidence of stability or disruption. Frequent daily reductions in sleep duration below six hours are associated with degradation of alertness and performance of physical and mental tasks. Daily shifts in sleep and wake-up times, and in the subsequent timing of daily daylight exposure, disrupt the regulation of the body's biological rhythms and also result in degradation of performance and alertness.

Sleep/wake cycle histories were examined in records containing at least five consecutive days (e.g., see segments in Figures 4-6). In each segment, the magnitude and frequency of changes in sleep and wake-up times, the duration of the sleep period, and the incidence of increased activity during sleep were quantified using a seven-point scale. The scale values, herewith referred to as the Circadian Disruption Index (CDI) values, were used to indicate the degree of disruption or stability of each segment of five or more consecutive 24-hour days.

The highest disruption value (seven) was used to indicate evidence of persistent irregular bedtimes and wake-up times and of splitting of the sleep period (fragmentation). The term "fragmented sleep" is used to indicate that daily sleep was broken up into at least two segments (e.g., one period of three hours during nighttime and one period of four hours during daytime hours). Figure 6 depicts a sleep/wake cycle segment corresponding to a CDI value of seven. Note the occurrence of sleep fragmentation and daily advances and delays of bedtimes and wake-up times (arrows). Daily sleep must take place in consolidated and uninterrupted periods of at least six hours (in quiet and dark environments) to prevent performance degradation during waking hours (OTA report, 1991). CDI values of six and five were used to indicate a high incidence of daily changes in sleep and wake-up times occurring in the absence of sleep fragmentation. Figure 5 depicts a sleep/wake cycle fragment corresponding to a CDI value of six.

CDI values of five, six, and seven characterize a physiological condition in which the body's internal regulation of energy becomes disrupted (shiftwork maladaptation). This condition is characterized by fatigue symptoms similar to those experienced by international travelers (Jet-Lag) crossing more than five time zones.

Low CDI values (one, two, and three) were used to characterize the transition from stable sleep/wake cycles (one) to increasing sleep loss and frequent awakenings (two to three). These CDI values were not associated with daily changes in sleep and wake-up times. The mid-range CDI value of four was used to label sleep/wake profiles exhibiting increasing, but infrequent, variations in sleep and wake-up times. Table 1 provides a detailed description of the quantifiable characteristics associated with each CDI value.

Table 1. Description of quantifiable characteristics associated with CDI values used to analyze circadian activity profiles.

CDI	Characteristics of Circadian Sleep/Wake Cycles
1	• Consistent sleep and wake-up times from day to day (e.g., changes no greater than one hour), and • Sleep duration of more than six hours per day, and • No sleep disruption (e.g., frequent awakenings), and • No sleep fragmentation
2	• Sleep duration of six hours or less in no more than one out of five days, and • Sleep disruption (e.g., frequent awakenings), and • No sleep fragmentation, and • No changes in sleep and wake-up times greater than one hour per day
3	• Sleep duration of six hours or less observed more than once every five days, and • No sleep fragmentation, and • No changes in sleep and wake-up times greater than one hour per day
4	• Changes in sleep and wake-up times of one hour or greater observed no more than once every five days, and • No more than one 24-hour period showing sleep fragmentation associated with daily changes of wake-up times
5	• Variation in bedtimes and wake-up times of one hour or greater observed more than once every five days, and • No more than one 24-hour period showing sleep fragmentation associated with daily changes of wake-up times
6	• Frequent variations in bedtimes and wake-up times greater than one hour (e.g., every two days or more observed in at least five-day periods), and • No more than one 24-hour period showing sleep fragmentation associated with daily changes of wake-up times
7	• Frequent variations in bedtimes and wake-up times greater than one hour (e.g., every two days or more observed in at least five-day periods), and • Sleep duration below six hours observed more than once every five days, or • Fragmentation of the sleep period in two or more bouts throughout the 24-hour period associated with daily changes of wake-up times

Using the CDI table to score the stability of sleep/wake patterns throughout 30 days underway, we found an incidence of sleep/wake cycle disruption of 61.5 percent (CDIs from five to seven) in a total of 83 segments obtained from the records of 39 volunteers. Severe disruptions of the sleep/wake cycle were associated with frequent changes of work schedules from daytime to the 0000-0400 watch and/or to the 0400-0800 watch.

Relationship between disrupted sleep/wake cycles and sleep loss

The frequent rotation of personnel from daytime watch schedules to nighttime and early morning duty times induced frequent variations in bedtimes and rise-times, and reductions of sleep duration. For each of the fourteen subjects participating in the alertness tests (MWTs), the loss of

sleep was documented by calculating the percent of consolidated sleep periods of less than six hours in each segment of the sleep/wake profile. The resulting sleep loss index (SLI) values were used to examine the strength of the association between disrupted sleep/wake cycles and sleep duration. This relationship was determined by calculating the correlation between SLI and CDI values from 30 sleep/wake cycle segments recorded from the MWT group ($n = 14$). Non-parametric correlation analysis (Siegel, 1958) revealed a significant positive association between increasing sleep/wake cycle disruption and sleep loss (Spearman $R = 0.74$, $p < 0.05$). The same analysis applied to 82 records from all participants ($n = 39$) resulted in a similar outcome (Spearman $R = 0.78$, $p < 0.05$).

Figure 7 illustrates the relationship between the frequency of sleep periods of less than six hours and sleep/wake cycle disruption (CDI values plotted on the horizontal axis) for the MWT group. Sleep periods with less than six hours (SLI scores plotted on the vertical axis) were observed consistently (SLIs above 0.4) in association with high incidence of sleep/wake cycle disruption (CDIs five to seven). Note that low SLI values (below 0.4) were largely restricted to CDI values at or below four. Only one observation (CDI = 4 and SLI = 1) is inconsistent with this notion (see Figure 7). These observations indicate that participants rotating into watch schedules that disrupt the stability of the sleep/wake cycle experienced a reduction in the energy restorative value of their sleep. Rotations from daytime watch schedules into the 0000-0400 and 0400-0800 would meet such description.

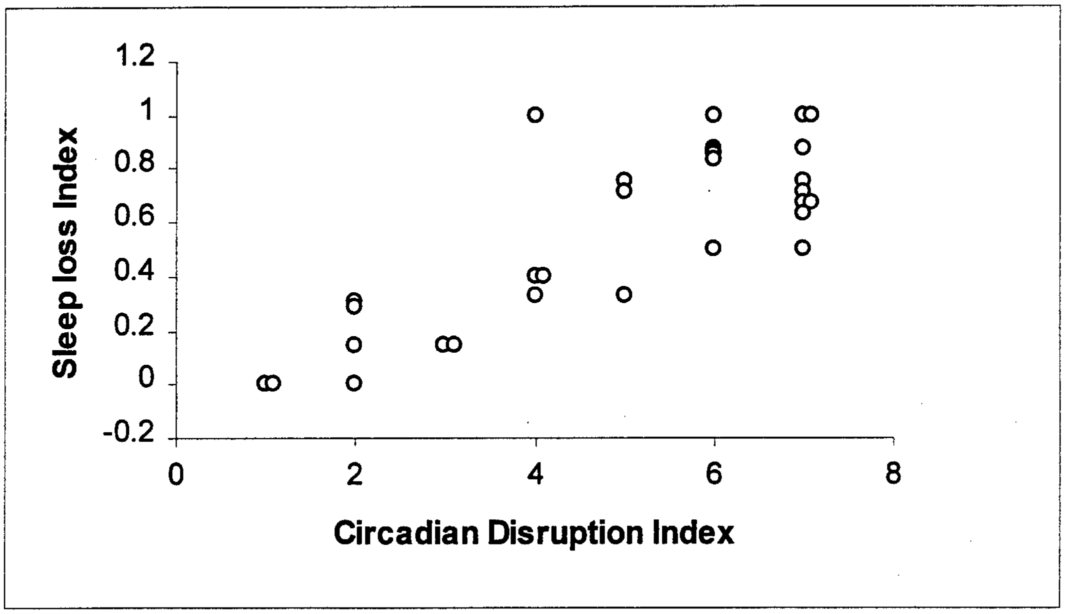


Figure 7. Percentage of sleep periods of less than six hours are plotted as a function of increasing sleep/wake cycle disruptions (Circadian Disruption Index). CDIs and SLIs were calculated for 30-sleep/wake cycle segments obtained from 14 MWT participants. The strength of the association between these variables (Spearman $R = 0.74$, $p < 0.05$) indicates that sleep loss was a common occurrence when watch schedules required shifts in wake-up times.

In the following section, we examined the association of disrupted sleep/wake cycles with the ability to maintain wakefulness during the alertness tests. Our intent was to determine whether disrupted sleep/wake cycles (as denoted by high CDI values) were associated with poor performance in the MWT.

<u>Relationship between disrupted sleep/wake cycles and alertness reduction</u>

For each participant, a wakefulness reduction index (WRI) score was calculated by determining the percent of tests with MWT scores below 8.2 minutes. The 8.2-minute threshold indicated degradation of alertness at either pathological levels (at or below five minutes) or at levels indicating shiftwork maladaptation as reported by Campbell and Dawson in the 1997 report. Further analyses were conducted to determine whether a relationship existed between disrupted sleep/wake cycles (CDI scores) and evidence of alertness reduction as indicated by the WRI values. For this purpose, the relationship between alertness reduction levels and the degree of

disruption of sleep/wake cycles was determined by calculating the correlation between CDI and WRI values from 30 sleep/wake cycle segments obtained from the MWT group ($n = 14$). Non-parametric correlation analysis revealed a significant positive association between increasing sleep/wake cycle disruption and increasing alertness reduction (Spearman $R = 0.67$, $p < 0.05$). Figure 8 illustrates the systematic increase in the percentage of failed alertness tests scores (WRI scores plotted on the vertical axis) as a function of increasing sleep/wake cycle disruption, indicated by CDI scores plotted over the horizontal axis. Note that wakefulness reduction also occurs in association with stable sleep/wake cycles (CDIs of two to four), but these observations occur less consistently than in cases associated with high CDIs (five to seven).

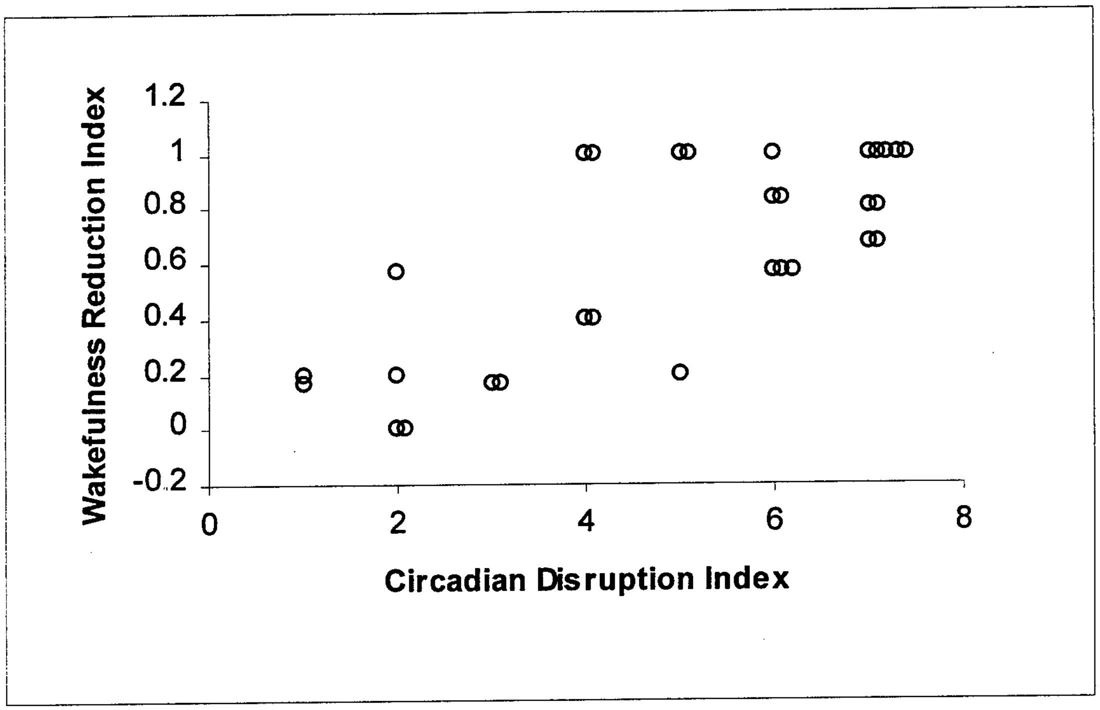


Figure 8. **Percentage of scores below 8.2 minutes (Wakefulness Reduction Index) is plotted as a function of increasing sleep/wake cycle disruptions. WRIs and CDIs were calculated for a total of 30 sleep/wake cycle segments obtained from 14 participants. The strength of the association between these variables (R= 0.67, Spearman, p < 0.05) indicates that alertness degradation after normal sleep was more frequently experienced in association with disrupted sleep/wake cycles.**

Breakdown of sleep/wake cycle disruption as a function of department membership

Figure 9 illustrates the frequency distribution of CDI scores broken down by departmental groupings. Participants were grouped as a function of similar duty assignments. Six groups were derived from duty assignments, namely, command staff (n = 1), operations (n = 5), weapons (n = 17), engineering (n = 9), mess/cook (n = 5), and support/administration (n = 2). Data from all 39 participants were used in this analysis.

Participants' sleep/wake cycle histories were broken down into segments of five or more days and scored for the degree of sleep/wake cycle disruption using the CDI scale from one to seven (refer to the methods section for detailed description). A total of 82 CDI values, corresponding to 82-sleep/wake cycle segments from the 39 participants, were distributed over the six groups. In Figure 9, each observation plotted on the vertical axes corresponds to the number of CDIs observed under each of the seven CDI categories. Note that CDI classifications between five to seven were more frequent in the engineering group (a total of 21 observations) than in any other departmental grouping. In addition, frequency distributions for operations, weapons, and mess/cook groupings show a considerable number of sleep/wake cycle segments classified under CDI scores of five to seven. These distribution patterns indicates that sleep/wake cycle disruption was frequently experienced by crew members in the engineering, operations, weapons, and mess/cook groups.

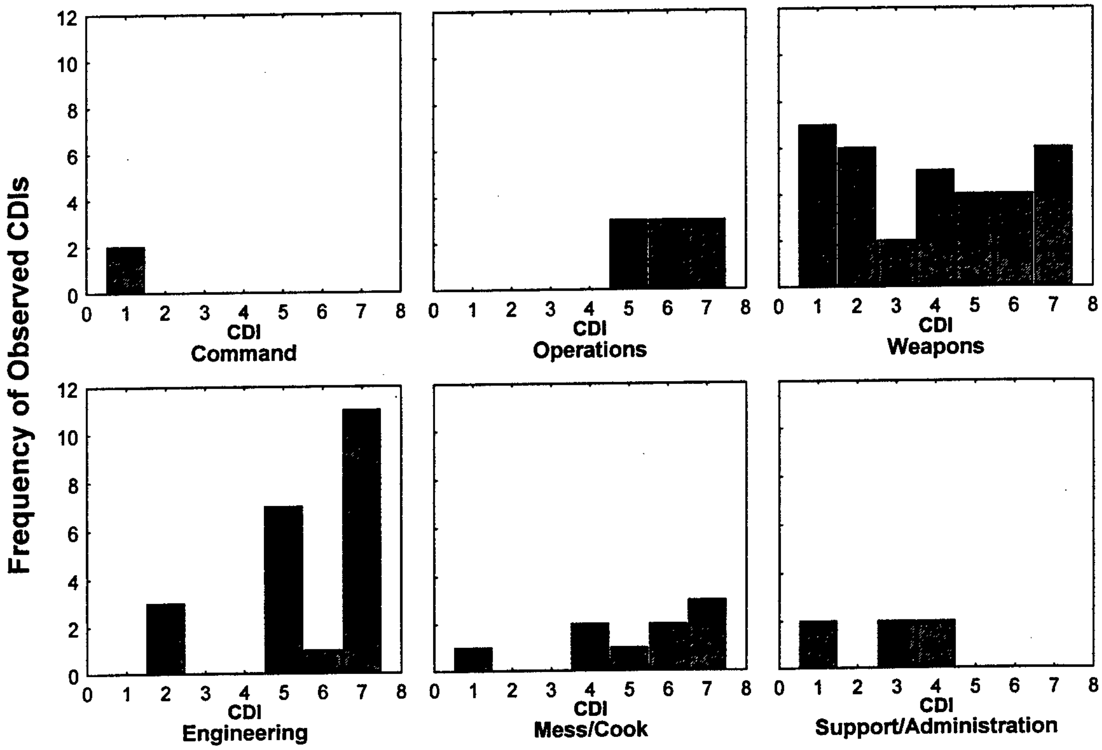


Figure 9. Frequency distribution of CDI scores (n = 82) for each departmental grouping. The majority of CDI scores in engineering, operations, and mess/cook groupings were distributed over higher levels of circadian disruption (five to seven). A bimodal distribution characterizes the weapons department with almost as many observations above (14) and below (15) a CDI of four.

Environmental Observations

Sleeping quarters

Examination of sleeping quarters revealed, in some cases, less than optimal ventilation and personal space in enlisted quarters, and in one specific case, noise levels that may disrupt sleep. Bunks were equipped with curtains that could be closed to prevent light intrusion during sleep and promote privacy in berthing areas housing 16 or more crew members. However, participants living in these quarters consistently reported that the use of curtains prevented air circulation throughout the bunk compartment. Bunks, in stacks of three or more, provide minimal clearance to the bottom of the bunk above. Personnel with large body frames (e.g., six-foot in height) are likely to make contact with the bottom of the upper bunk while changing body positions (i.e., rolling over) during sleep. Although, direct experimental evidence is not available, it is possible

to assume that changing body positions under these conditions may disrupt the continuity of sleep.

Noise level measurements using a sound pressure level (SPL) meter revealed a constant noise source of 80 dB (A) at 1 kHz in berthing area 2-96-1-L, housing enlisted crew members (see Table A-2, Appendix A). The noise source was traced to the Gyrocompass room. This noise level is within the range that has been found to disrupt sleep when presented in brief intervals under three minutes (Miller, 1974). The impact of continuous exposure to noise may temporarily affect hearing sensitivity. EPA hearing conservation guidelines recommend minimizing exposure to noise levels above 75 dB(A) (Environmental Protection Agency, 1978), while Department of Defense recommends a limit of 84 dB(A) (Department of Defense, 1978).

The impact of 80 dB(A) at 1 kHz on hearing may depend on individual susceptibility and duration of exposure. However, considering all of the environmental issues discussed in this section, it is reasonable to conclude that sleep environments were less than optimal, particularly in the case of enlisted berthing areas.

CONCLUSIONS AND RECOMMENDATIONS

The observation that nine out of 14 participants failed to maintain wakefulness above 8.2 minutes in the majority of all trials strongly suggests that these participants experienced severe alertness degradation throughout the 30 days of the study (see Figure 3). The documentation of frequent sleep/wake cycle disruptions, and their association with frequent failure to maintain wakefulness in the alertness test, supports the notion that watch schedules contributed to the degradation of alertness. The daily changes in watch schedules and rise times resulted in unstable sleep/wake cycles. This condition provided inconsistent inputs to the internal biological clock and disrupted the timing and continuity of the sleep period.

Experimental and clinical evidence indicates that rapid shifts in work schedules have a detrimental impact on health and physiological well being (Kogi, 1985; Scott & Landou, 1990;

Smolensky & Reinberg, 1990; Office of Technological Assessment [OTA], 1991). In general, varying reporting times from day to day is often associated with the disruption of the sleep/wake cycle, sleepiness, reduced alertness, deterioration of performance, and physical discomfort associated with gastrointestinal disorders (Comperatore & Krueger, 1990; Monk, 1990; OTA, 1991). The frequent changes in rise times exhibited by crew members implies that their biological clock may have received inputs causing frequent timing readjustments from day to day. These variations would be expected to induce changes in alertness greater in magnitude than the sleepiness reported by the lay person during the transition to daylight savings time. Usually this change is only a one-hour advance in rise time and daylight exposure time (in the morning), yet it is well documented that the U.S. population at large experiences sleepiness and an increase in the rate of automobile accidents during the first week of the change. In the case of MUNRO's crew exposed to the 0000-0400 or 0400-0800 watch schedules, their changes in rise times varied by more than three hours and occurred several times within a month or sometimes within a week.

Lack of alertness cannot be solely attributed to the impact of watch schedules since personal sleep habits, operational tempo, and seasickness are also significant contributors to sleepiness and fatigue. Individual choices may impact crew rest as personnel decide whether or not to take advantage of rest opportunities after duty hours. Training for crew members on how to maximize crew rest can help optimize the restorative value of available rest opportunities (Comperatore 1996).

Crew members' work hours averaged approximately 64 hours per week. This patrol was characterized by low operational tempo. Helicopter operations were conducted twice per day during the normal duty day (0700-1600). Boarding activities were infrequent (four boardings during the study period) and occurred during daytime duty hours. Therefore, relative to operational scenarios with higher incidence of boardings and helicopter operations after 1600, MUNRO's crew experienced predictable workdays ending at 1600.

During the study period, sea states ranged from two to seven feet and weather conditions were largely unremarkable. We assume that doing business at sea always carries the physiological cost that ship's motion imposes on alertness levels. In high seas, increased levels of physical

fatigue, in addition to seasickness, are likely to occur as the range of ship motion increases. The actual physiological impact of seasickness varies with the effects of sea states on ship's motion and with individual physiological responses to motion. While the effects of motion discomfort are difficult to control without pharmacological interventions, we can effectively minimize fatigue associated with watch schedules via the implementation of more stable schedules.

It should be noted that the architecture of the watch schedule used on the MUNRO during the study period prescribed frequent rotations from daytime to nighttime duty hours. One characteristic of watch schedules that directly affects sleep duration, and the stability of the sleep/wake cycle, is the frequency of rotation from daytime to nighttime duty hours. For instance, rotating from daytime duty hours (e.g., reporting time at 0700) to nighttime work schedules (e.g., 0400-0800 watch) within a 24-hour period induces sleep loss and disrupts the biological clock's synchronization with the sleep/wake cycle. Implementing this schedule several times within a week will prevent the biological clock from effectively managing physiological and cognitive resources (physical energy and mental ability).

In contrast, slowing the rotation to a two-week interval will allow crew members to adapt to the new work schedule. The adaptation takes place as the biological clock resynchronizes physiological, biochemical, and cognitive functions with the sleep/wake cycle. For instance, stabilizing a crewmember's watch schedule to two consecutive weeks in the 0400-0800 watch will be less disruptive than alternating the 0400-0800 with the 0800-1200 watch schedule every other day. Although the alternating schedule may seem to relieve the crewmember from getting up early every morning, it actually results in inconsistent inputs to the biological clock (Figure 5). In this case, wake up time varies from 0330 to 0630 every other day. Since the biological clock takes approximately 72 hours to re-adjust rhythms to a new sleep/wake cycle and the accompanying changes in exposure to daylight, it cannot respond fast enough in frequently rotating watch schedules as in Figures 5 and 6. Reducing the frequency of the watch schedule rotation (e.g., two weeks rotation) allows the biological clock to adapt to the new work schedule in the first three days and to maintain a steady state of synchronization for the remainder of the two weeks. During this period, the individual reaps the benefits of a stable sleep schedule and the

potential to maximize the benefits of each rest period. Figure 4 supports this notion and depicts the stability of the sleep/wake cycle under a constant 0400-0800-watch schedule.

Watch schedule rotation frequency of two weeks or more will reliably result in stable sleep/wake cycles, better sleep quality, and more consistent duration of the sleep period. Under slowly rotating watch schedules, CDI values will remain within one to four and alertness degradation can be expected to be minimal under good weather conditions. Wakefulness tests can be expected to yield failure rates below 50 percent. However, motion discomfort, resulting from individual physiological differences and sea states will remain a significant contributor to the physiological cost of doing business at sea.

Personnel reductions, low qualified/unqualified personnel ratios, and operational tempo will require increasing the frequency of watch rotations. Under Exemplar prescribed crew reductions, watch schedules requiring high rotation frequencies will inevitably induce fatigue and performance degradation. However, prevention of these side effects may be accomplished by:

- implementing crew endurance plans to reduce the frequency of rotations into the 0000-0400 or 0400-0800 watch schedules,
- designing watch schedules that minimize circadian disruption of sleep/wake cycles
- maximizing the number of watch qualified crew members prior to departure, and
- improving ventilation, reducing noise, minimizing pipings until 1000, and increasing personal space (when possible) in sleeping quarters.

Unfortunately, under current conditions, the combination of proposed crew reductions and increased operational tempo are likely to induce significant reductions in alertness and endurance, thus compromising safety and efficiency in most USCG mission profiles at sea.

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Table A-1. MWT Latency Table

Participant	Date	MWT	No. MWTs	%<8.2	%<10
16	2-May	4.75	5	100	100
16	5-May	1.08			
16	8-May	6.18			
16	14-May	2.58			
16	23-May	4.66			
19	3-May	11.46	5	80	80
19	5-May	1.36			
19	8-May	2.08			
19	15-May	1.28			
19	19-May	0.25			
25	30-Apr	15	6	20	20
25	6-May	11.08			
25	12-May	15			
25	15-May	15			
25	19-May	5.91			
25	21-May	15			
29	1-May	15	6	33	50
29	4-May	15			
29	7-May	8.33			
29	15-May	3.58			
29	16-May	15			
29	19-May	5.5			
34	1-May	5.91	7	42	86
34	4-May	2			
34	7-May	8.3			
34	13-May	15			
34	16-May	9.5			
34	21-May	7.66			
34	22-May	5.58			
38	2-May	15	6	33	33
38	12-May	5.41			
38	16-May	15			
38	20-May	15			
38	21-May	15			
38	23-May	5.08			
44	2-May	1.31	5	100	100
44	5-May	0.8			
44	8-May	2.66			
44	14-May	4.16			
44	25-May	4.33			

Table A--1. MWT Latency Table (continued)

Participant	Date	MWT	No. MWTs	%<8.2	%<10
49	2-May	4	7	100	100
49	4-May	3.16			
49	7-May	2.16			
49	13-May	1.58			
49	16-May	3.15			
49	19-May	5.31			
49	21-May	1.25			
52	1-May	5.33	6	83	83
52	4-May	5			
52	7-May	2.75			
52	13-May	2.08			
52	17-May	10.2			
52	19-May	0.9			
55	30-Apr	15	6	0	0
55	3-May	15			
55	6-May	15			
55	12-May	15			
55	15-May	15			
55	20-May	15			
60	1-May	0.33	5	20	20
60	4-May	15			
60	7-May	15			
60	13-May	15			
60	16-May	15			
65	30-Apr	11.25	7	57	57
65	6-May	3			
65	9-May	15			
65	12-May	4.16			
65	14-May	4.46			
65	19-May	15			
65	21-May	4.91			
70	2-May	6.5	6	67	83
70	6-May	1.5			
70	8-May	8.33			
70	14-May	15			
70	20-May	4.66			
70	22-May	6			
71	30-Apr	5.16	6	100	100
71	6-May	1.66			
71	12-May	1.41			
71	15-May	1.5			
71	20-May	0.58			
71	22-May	2.58			

Table A-2. Noise Level Recordings

Berthing Area	Frequency	Location 1	Location 2	Location 3	Location 4	Location 5
2-256-2-L		dB				
	125 Hz	68	68	69	66	67
	250 Hz	66	60	62	59	65
	500 Hz	50	55	59	50	58
	1.0 kHz	54	53	50	45	50
	2.0 kHz	52	50	49	46	48
	4.0 kHz	47	46	46	40	42
	8.0 kHz	40	35	39	30	35
2-290-1-L	125 Hz	60				
	250 Hz	60				
	500 Hz	52				
	1.0 kHz	56				
	2.0 kHz	49				
	4.0 kHz	49				
	8.0 kHz	-				
2-96-1-L	125 Hz	59	62	64	60	
	250 Hz	56	56	62	60	
	500 Hz	59	60	67	68	
	1.0 kHz	62	65	65	**80**	
	2.0 kHz	45	50	50	54	
	4.0 kHz	40	46	44	44	
	8.0 kHz	-	-	30	30	

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